



NASA Electronic Parts and Packaging (NEPP) Program

2014 NEPP Tasks Update for Ceramic and Tantalum Capacitors

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**Work performed for Parts, Packaging, and
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NASA GSFC, Code 562**

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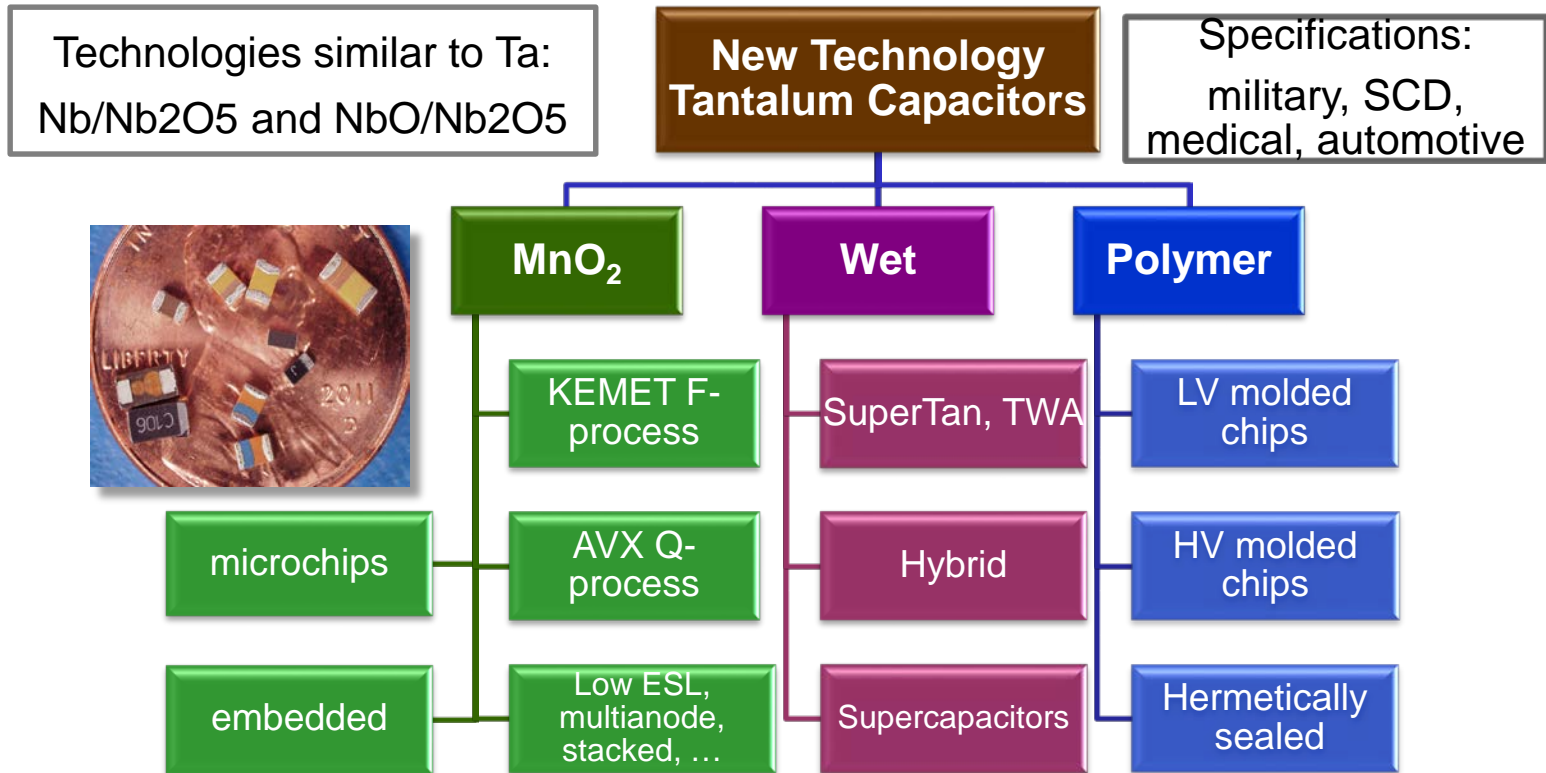
List of Acronyms and Symbols

AF	acceleration factor	MLCC	multilayer ceramic capacitor
BME	base metal electrode	MSL	Moisture sensitivity level
C	capacitance	PME	precious metal electrode
DCL	direct current leakage	PV	Prokopowicz-Vaskas
DF	dissipation factor	S&Q	screening and qualification
DWV	dielectric withstanding voltage	STD	Standard deviation
ESR	Equivalent series resistance	T	temperature
HALT	highly accelerated life testing	THB	temperature, humidity, bias
HSSL	humidity steady state low voltage	TSD	terminal solder dip
HT	High temperature	TTF	time to failure
HV	high voltage	VBR	breakdown voltage
IM	Infant mortality	VBR₇₅	third quartile of VBR distribution
IR	insulation resistance	V_O⁺⁺	charged oxygen vacancy
LV	low voltage	VR	rated voltage

Outline

- ❑ Update on tantalum capacitors.
 - MnO₂ chip capacitors.
 - Advanced wet capacitors.
 - Polymer capacitors.
 - Future work.
- ❑ Update on ceramic capacitors.
 - Low-voltage failures in MLCCs.
 - IR degradation of BME capacitors caused by oxygen vacancies.
 - The significance of breakdown voltages for quality assurance of BME capacitors.
 - Effect of soldering.
 - Future work.

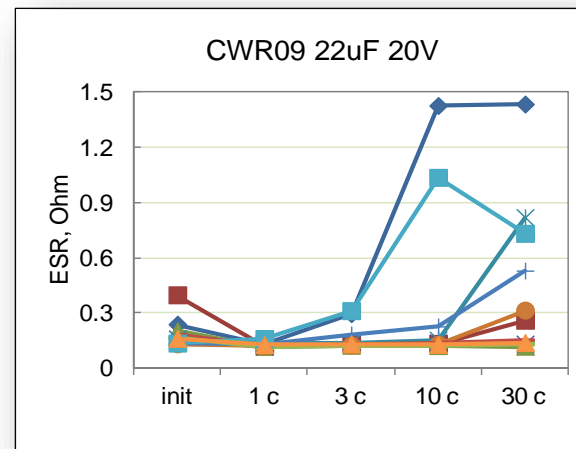
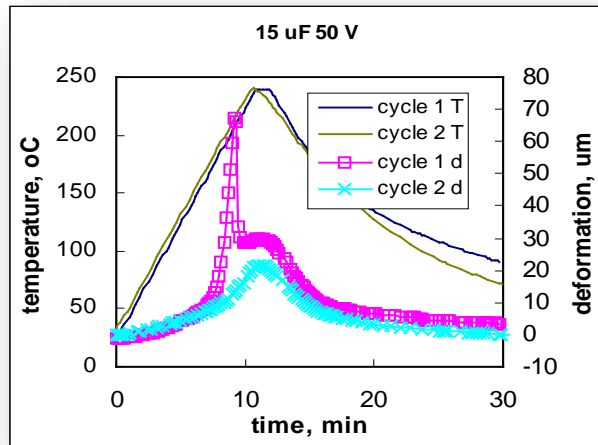
Diversity of Tantalum Capacitors



- ✓ Diversity is due to the variety of cathode systems.
- ✓ A general trend: reduction of size and ESR, increase in C, VR, and T_{oper}.
- ✓ New technologies appear with increasing speed.

Updates on MnO₂ Tantalum Capacitors

- ❑ Projects problems with capacitors appear with ~constant rate.
- ❑ Deficiencies in M55365 and new screening processes are in line with NEPP recommendations.
 - KEMET F-technology – importance of VBR.
 - AVX Q- technology – Weibull grading, HT DCL, reflow...
- ❑ Pop-corning and MSL.

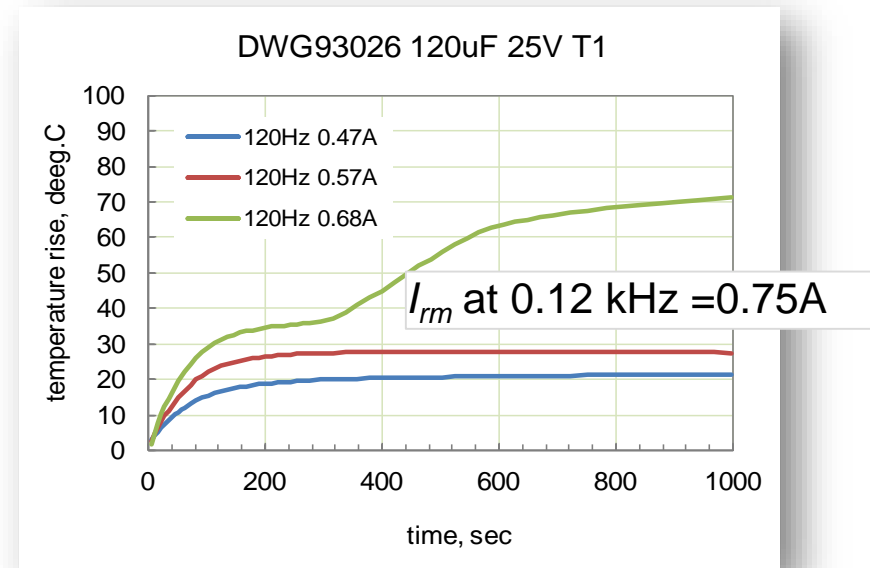


- ✓ Baking to avoid pop-corning.
- ✓ Multiple soldering cycles might degrade ESR and DCL.
- ✓ Recent projects' failures (linear regulator oscillated due to increased ESR, first turn-on failures)

Updates on Wet Tantalum Capacitors

- ❑ Reverse bias effects are similar to solid tantalum capacitors but might cause more dramatic consequences.
- ❑ Ripple current testing and requirements for rating and derating for applications in vacuum.
- ❑ Vibration testing of various types of capacitors is work in progress.

Failure in vacuum chamber

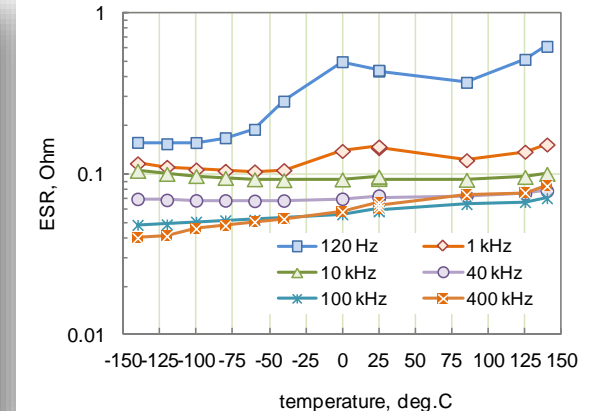
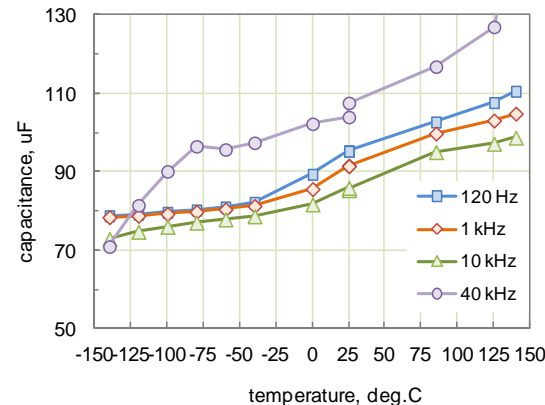
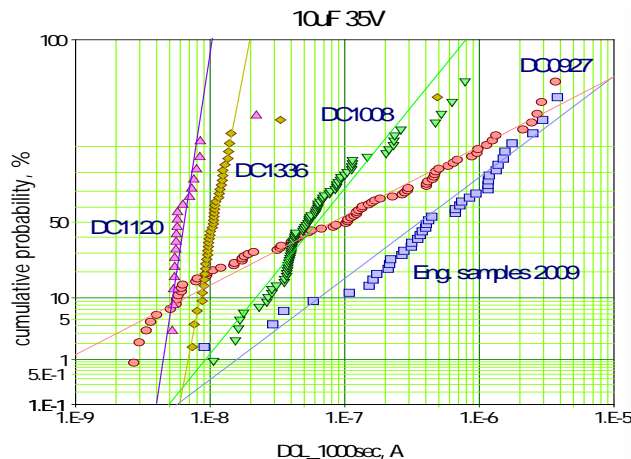


Thermal run-away in vacuum happened at currents below I_{rm} .

- ✓ Guidelines for S&Q have been updated to include ripple current requirements.
- ✓ Requirements for vibration testing should be specified.

Updates on Polymer Capacitors

- ❑ Characteristics of various types of chip and hermetic polymer tantalum capacitors are monitored since 2009.
- ❑ Substantial progress in performance and quality, especially for HV capacitors.



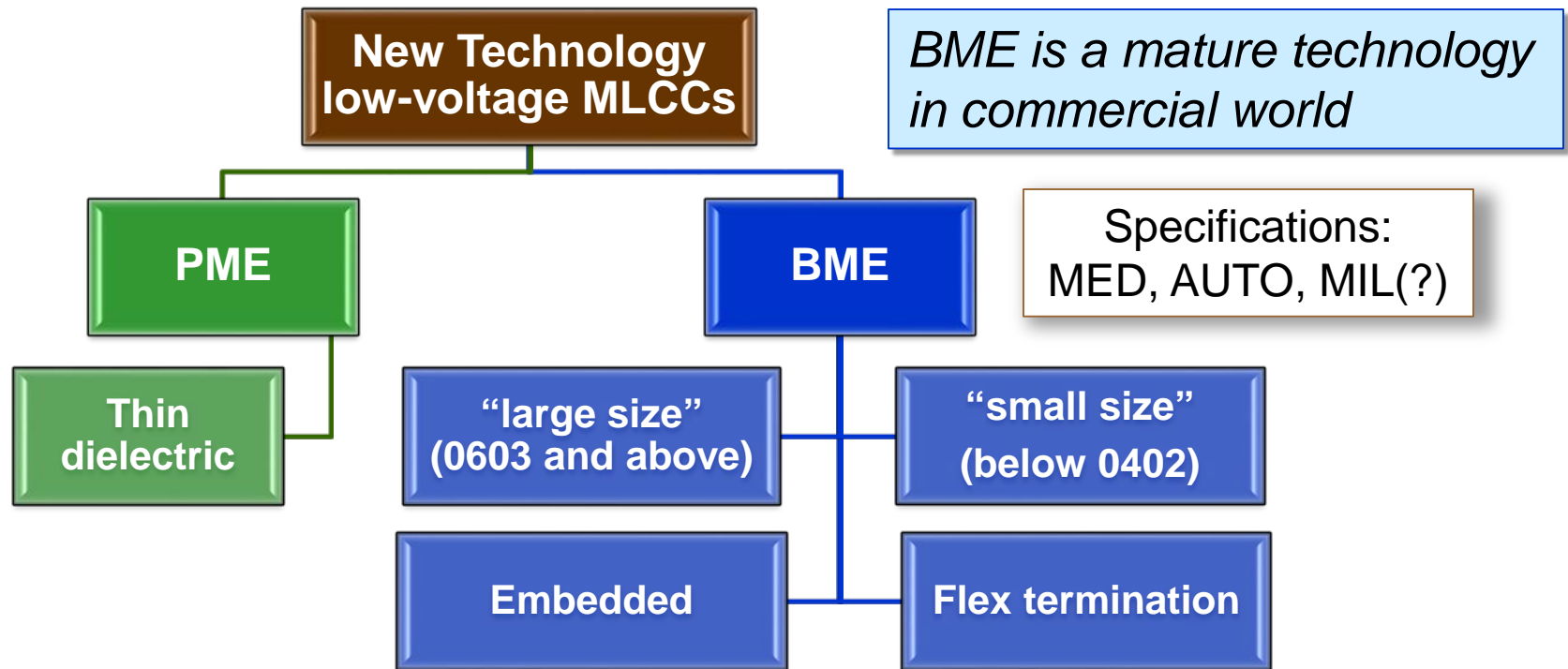
- Chip capacitors are still not ready for space applications.
- Hermetically sealed capacitors are good candidates for space, especially for low-temperature applications.
- High-temperature performance still remains a problem.

Future Work on Tantalum Capacitors

High CV parts require improved S&Q procedures.

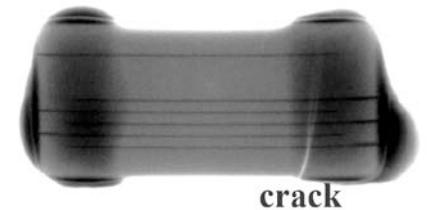
- ❑ MnO₂ chip capacitors.
 - Leakage currents and requirements for HT DCL.
 - MSL issues and requirements for manual soldering.
- *Requirements for DCL and conditioning for soldering.*
- ❑ High volumetric efficiency wet capacitors.
 - Leakage currents, gas generation, and requirements for wet.
 - Analysis of requirements for vibration testing.
 - Effect of HT storage.
- *Requirements for DCL and vibration testing.*
- ❑ Polymer capacitors:
 - Evaluation of automotive industry parts.
 - Hermetically sealed capacitors.
- *Assessment of performance at high temperatures.*

New Technology MLCCs

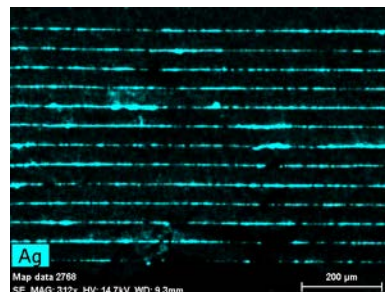
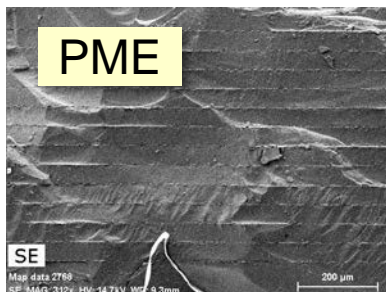
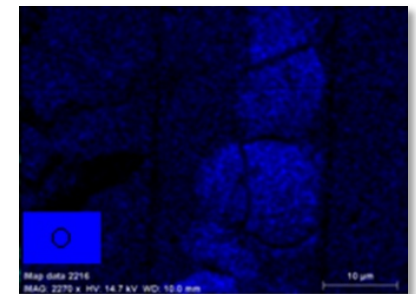
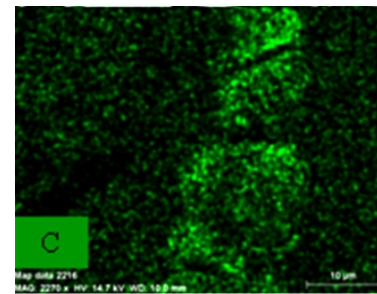
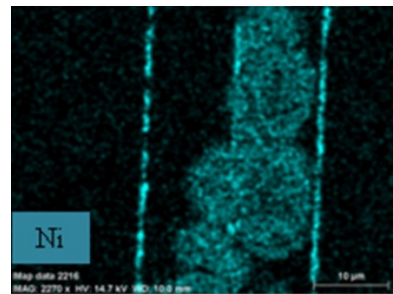


- ❑ The electrode system in MLCCs is limited to two materials.
- ❑ Diversity is due to variety of ceramic compositions and processes.
- ❑ Two major issues with MLCC:
 - Cracking-related low-voltage failures;
 - Oxygen-vacancies-related IR degradation.

Low-Voltage Failures



- ❑ HSSLV testing of various types of PME and BME capacitors showed that all PME capacitors with cracks failed, compared to 16% for BME.
- ❑ Failed BME capacitors had much greater IR.
- ❑ Cracks in BME can be revealed by THB testing at $V \gg 1.3V$.
- ❑ Manual soldering have a detrimental effect on MLCCs with defects.



- Probability of failures for PME is greater than for BME capacitors.
- The difference is due to the specifics of electro-chemical behavior of Ni and Ag/Pd and formed products.
- HSSLV testing is not effective for BME.

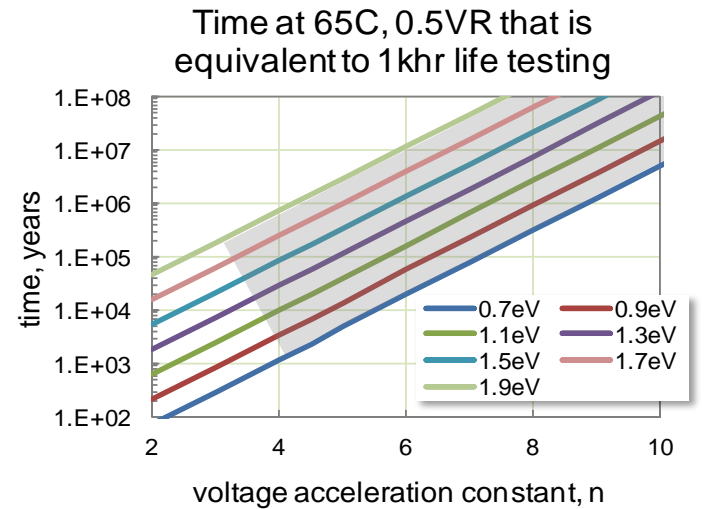
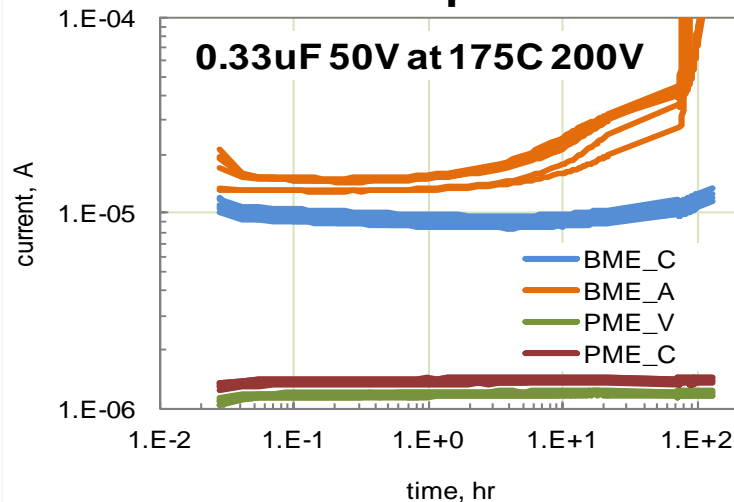
IR Degradation

- It is assumed that reliability of BMEs is limited by V_O^{++} .
- The wear-out problem is still there, but it has been moved out of application conditions by using new materials and processes.

(Life testing (1000 hr, 2VR, 125 °C) is equivalent to thousands of years at 65 °C and 0.5 VR).

$$AF = \left(\frac{V_2}{V_1} \right)^n \times \exp \left[\frac{E_a}{k} \left(\frac{1}{T_1} - \frac{1}{T_2} \right) \right]$$

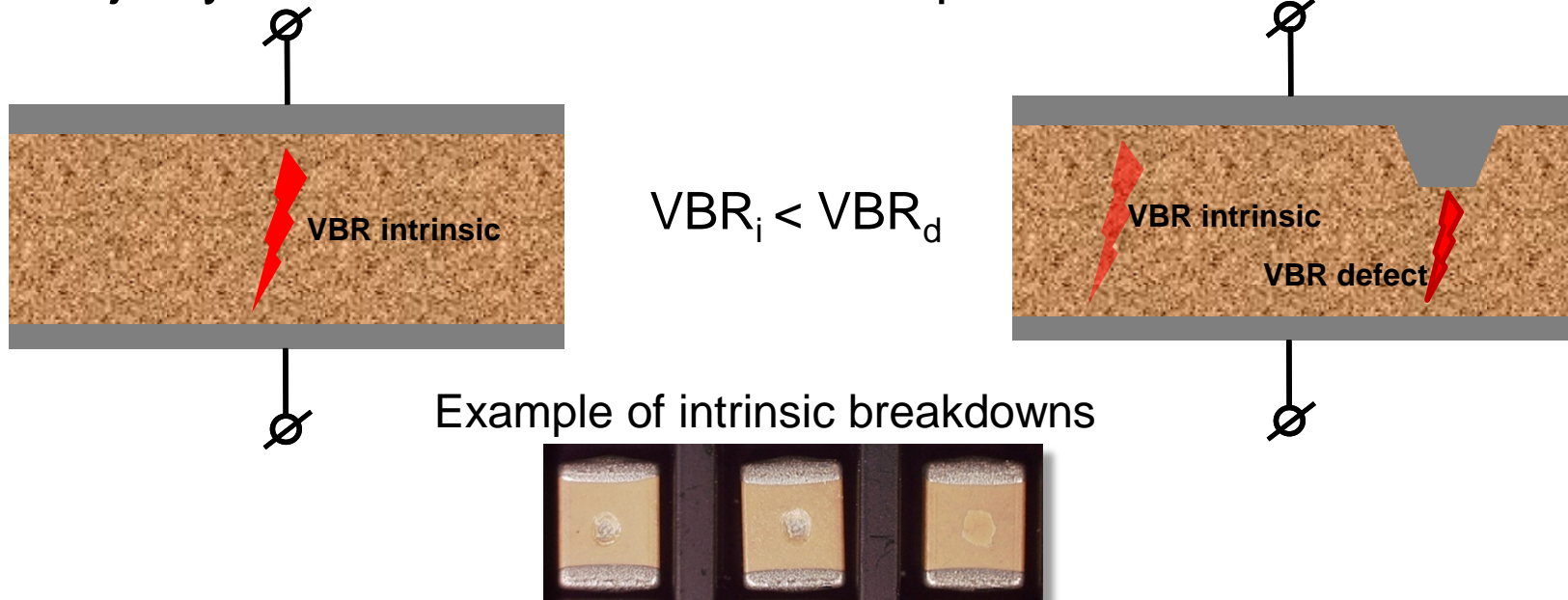
BME and PME capacitors at HALT



- Intrinsic wear-out failures due to V_O^{++} do not affect applications.
- Failures in the systems are caused by manufacturing or assembly-introduced defects.

Detection of Defects

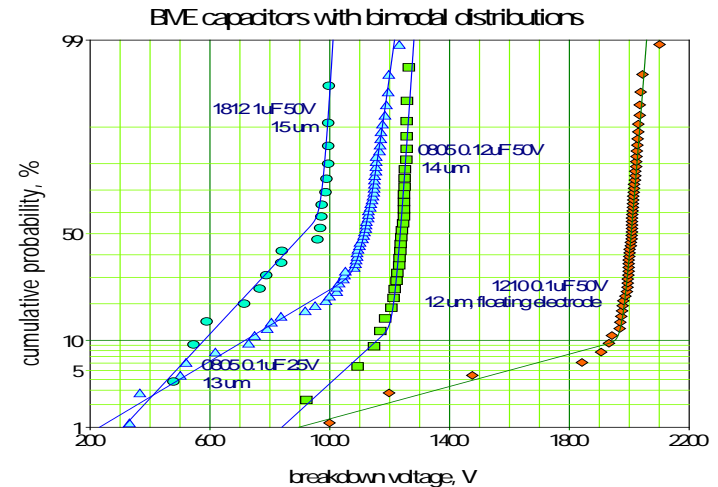
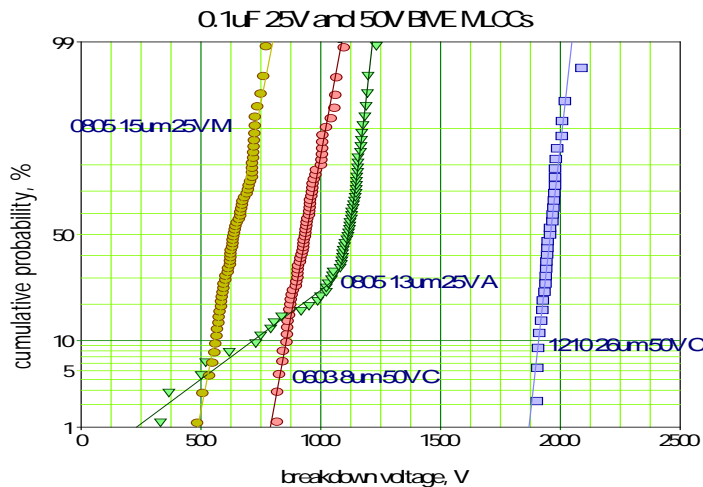
- ❑ Local defects do not change C, DF and IR, but affect VBR.
- ❑ Majority of MLCCs with defects can pass DWV test.



- ✓ High values of VBR (similar to IR) provide assurance that the parts have no gross defects that might cause failures.
- ✓ The consistency of VBR distributions indicates stability of the manufacturing process and quality of the product.

Distributions of VBR

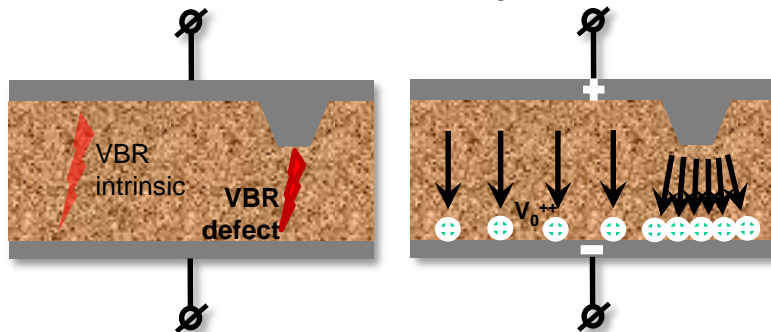
- ❑ In most cases distributions of VBR for BME capacitors are bimodal.
- ❑ The HV mode has tight distributions (STD/Mean ~4%) indicating intrinsic breakdown.
- ❑ The presence of LV subgroup is due to defects.



- ✓ The interception point indicates proportion of defects.
- ✓ The spread of VBR towards low voltages indicates the significance of defects.
- ✓ Lot acceptance criterion: $VBR_{min}/VBR_{75} > 0.5$.

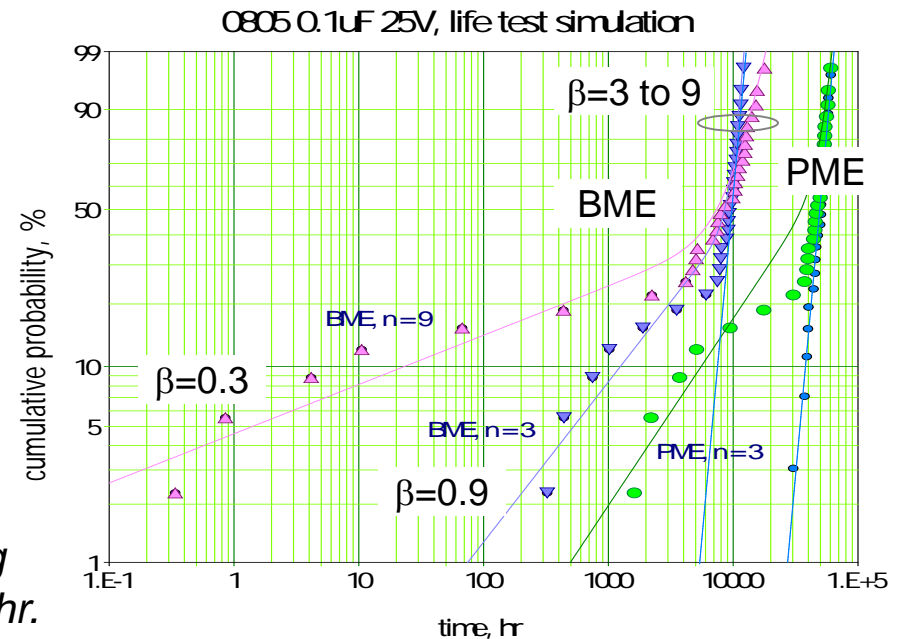
Reliability of MLCCs with Defects

Assumptions: intrinsic degradation for a defect-free part results in failures at TTF_0 and the voltage AF follows PV equation with $n \sim 3$ for PME and n from 4 to 9 for BME capacitors.



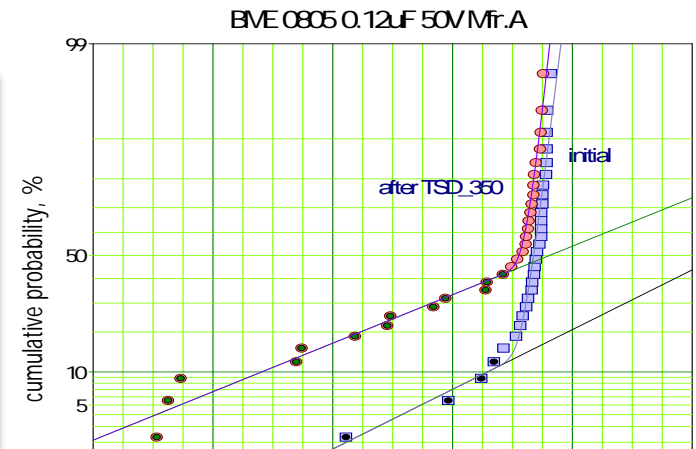
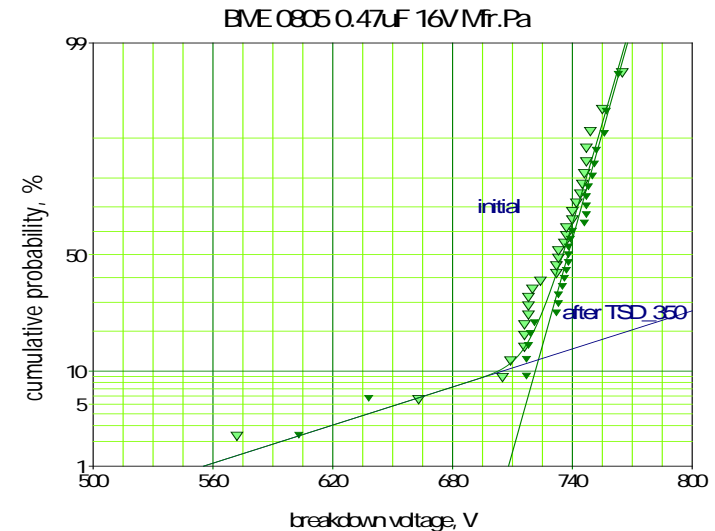
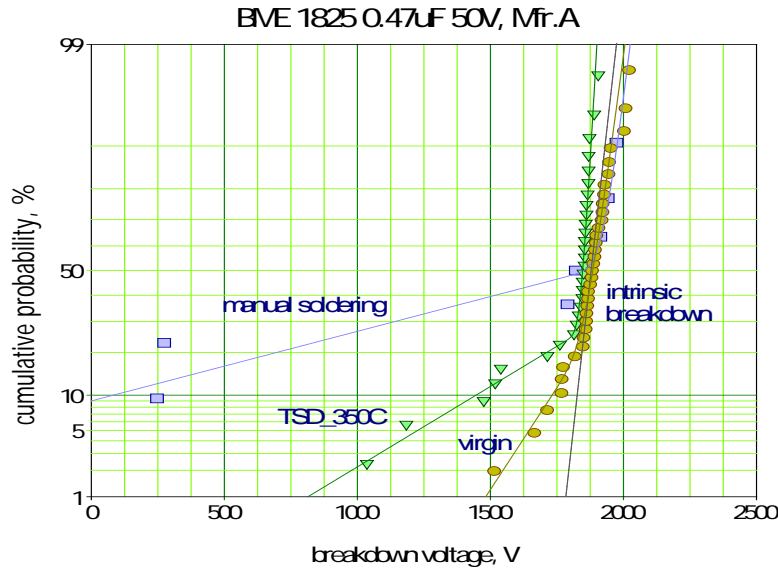
$$TTF = TTF_0 \times \left(\frac{VBR_d}{VBR_i} \right)^n$$

TTFs were calculated based on VBR assuming for PME $TTF_0=50$ khr, and for BME $TTF_0=10$ khr.



- ✓ Wear-out degradation in BME capacitors with defects results in IM failures.
- ✓ The greater the voltage acceleration constant n and the lower VBR/VBR_{75} , the more probable IM failures are.

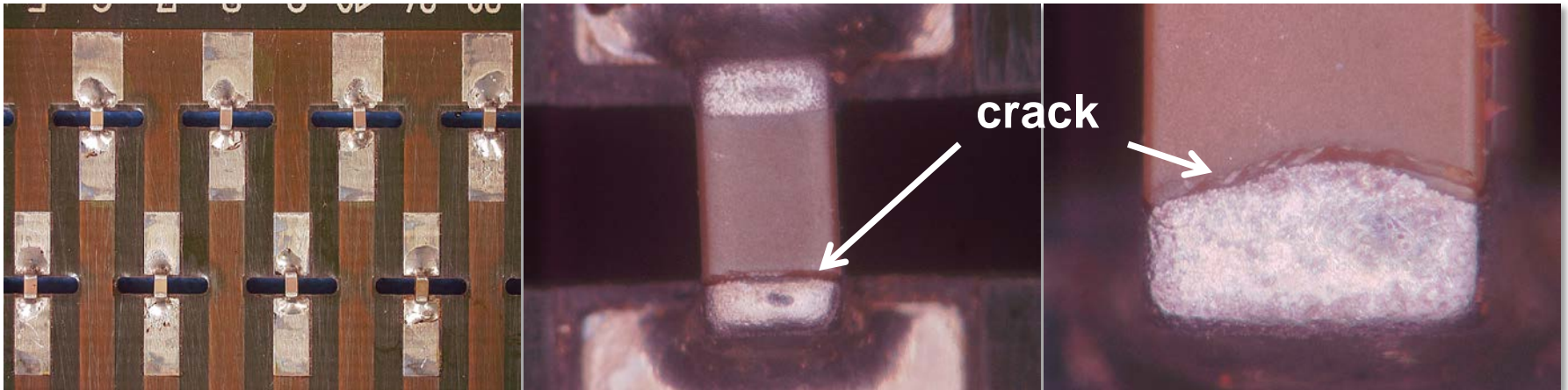
Effect of Soldering Stresses on VBR



- ✓ Some lots are sensitive to TSD stress.
- ✓ Stresses related to manual soldering can degrade VBR.
- ✓ VBR can be used as one of tests to qualify MLCCs for manual soldering.

Effect of Soldering

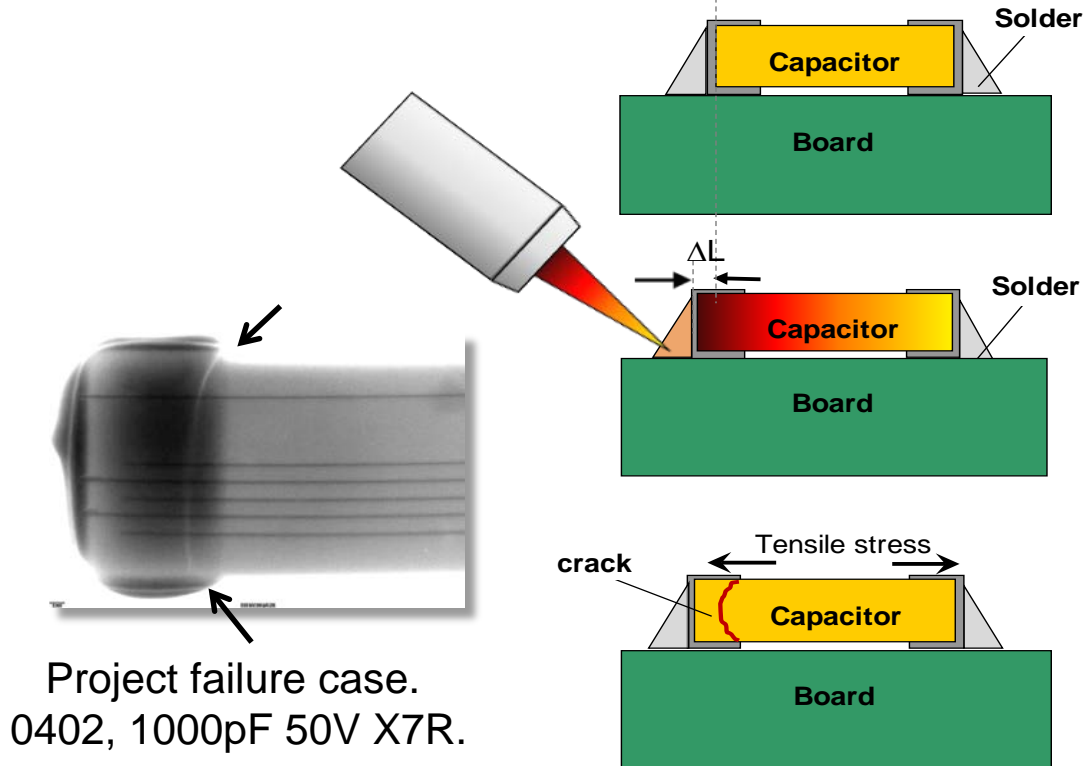
- ❑ It is often assumed that large size MLCCs are more vulnerable to cracking.
- ❑ Out of 40 samples of 0603 size MLCCs soldered with a soldering iron set to 315°C, 10 samples had intermittent or no contact.
- ❑ Failures were due to cracks along the terminations.
- ❑ No failures when parts were soldered onto a board preheated to 150°C.



- ✓ Manual soldering can cause cracking of small size capacitors.
- ✓ Preheating of the board is critical to reduce the probability of failures.

Effect of Soldering, Cont'd

- ❑ Post-soldering touch-up to improve the attachment might result in tensile stresses.
- ❑ Tensile stresses can cause cracking.



- ✓ To decrease the probability of fracturing during soldering, both, the reduction of the level of stress and selection of robust capacitors are necessary.

Future Work on Ceramic Capacitors

- ❑ Defect-related mechanism of failures at HT.
 - *Requirements for screening.*
- ❑ Effect of manual soldering conditions on reliability.
 - *Requirements for qualification testing.*
- ❑ Comparative analysis of performance and reliability of PME and BME capacitors:
 - Leakage currents.
 - Breakdown voltages.
 - Mechanical characteristics and the probability of fracturing.
 - *Recommendations for application.*
- ❑ Reliability issues related to assembly of small size MLCCs (0402 and less).
 - *Screening and qualification requirements.*